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Experimental assessment of steel fibre reinforced concretes with different concentrations of fibres

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Abstract At present, steel fibre reinforced concrete can be classified as a composite material commonly used for load-bearing building structures. Adding steel fibers to fresh mixture improves its mechanical properties in comparison to plain concrete. The problem is, however, the production technology, which has not been standardized by regulations so far, and thus, proposals for the amount of steel fibers added to the mixture are still based on the long-term experience and performed tests. The paper describes an experiment focused on the determination and assessment of mechanical properties of steel fibre reinforced concretes with high concentrations of fibres (40 kg/m³, 80 kg/m³ and 120 kg/m³). To better understand the behavior of test specimens during the three-point bending test, the acoustic emission method was used, which is able to capture active defects. The results show that the increasing amount of fibers has the influence on values of $F_{Rk,0.5}$ and $F_{Rk,res,1}$ (e.g. for concentration 40 kg/m³ is $F_{Rk,0.5} = 13.27$ kN and for 120 kg/m³ is $F_{Rk,0.5} = 21.18$ kN).

1. Introduction

Steel fibre reinforced concrete (SFRC) is a composite material with an added component of steel fibres guaranteeing an improvement of mainly the tensile load capacity and an increase in ductility. As a component, the fibres should be dispersed uniformly in the given volume, similarly, for example, to the dispersion of grains of the coarse fraction of aggregate in plain concrete. A uniform dispersion of steel fibers leads to a positive effect of their spatial action in the composite structure and to its overall stiffening. Steel fibers thus cannot be regarded as reinforcement in the traditional sense of the word but only as a solidifying element of the relatively fragile structure of plain concrete [1]. The use of various types of SFRCs is increasingly frequent in the building practice. The times when this concrete was only used for slab constructions of large dimensions, such as floors of production plants, etc., are long gone. In the course of the last few years, SFRC has been used for the production of prefabricated products, architectural panels, structures in seismic areas, tunnel lining, hydraulic structures and many others [2, 3]. SFRC is very often used also for military defensive structures, in which the selected concentration of steel fibres is many times higher than in civil structures.

The greatest problem of this building material is its production technology. Each composite material thus presents a complication for technologists considering the fact that the resulting characteristics depend partly on the properties of individual components, and partly, primarily, on their proportions. The more components a composite material contains, the higher attention must be paid to its production and selection of the composite's individual parts [4]. The efficiency of dispersed fibers does not depend on cohesion only, what is also very important is the choice of their correct amount, concentration, and mainly their uniform distribution in the material's structure. Under homogeneous



steel fibre reinforced concrete, we understand a composite material in which the added steel fibres are uniformly distributed in the given volume and no direction of fibres significantly predominates. Some studies show that the final distribution of fibres depends on the process of pouring [5, 6]. For this reason, much attention is given to the technological procedure of manufacturing SFRC itself.

The criteria according to which the homogeneity of SFRC is assessed, have not been fixed yet. Under homogeneous hardened SFRC concrete, we understand a material with an acceptable dispersion of the results of its tensile strengths obtained in the prescribed tests, in which a potential inhomogeneity can manifest itself significantly [7]. To guarantee a homogeneity of SFRC concrete means to subordinate its production to the used fibres and their volume stage of stiffening.

2. Methods

Tensile strength in bending is in fact the most important laboratory test because tensile strength as such is considerably more important for SFRCs than for plain concrete. The test is performed with a controlled deformation and the specimen is loaded with one loading roller figure 1. The beam is loaded at a uniform rate in such a manner that the deflection in the middle of the beam under loading grows proportionally to time, i.e. at a uniform loading rate. During each test of individual test beams, the progress of loading and response $F_{Ri} - \delta_{ti}$ is recorded. For each diagram record obtained, it is necessary to determine force $F_{Rk, 0.5}$ with an agreed deflection of $\delta_{t,0.5} = 0.5$ mm and force $F_{Rk,res,1}$ with an agreed deflection limit of $\delta_{t1} = 3.5$ mm in the middle of the span.

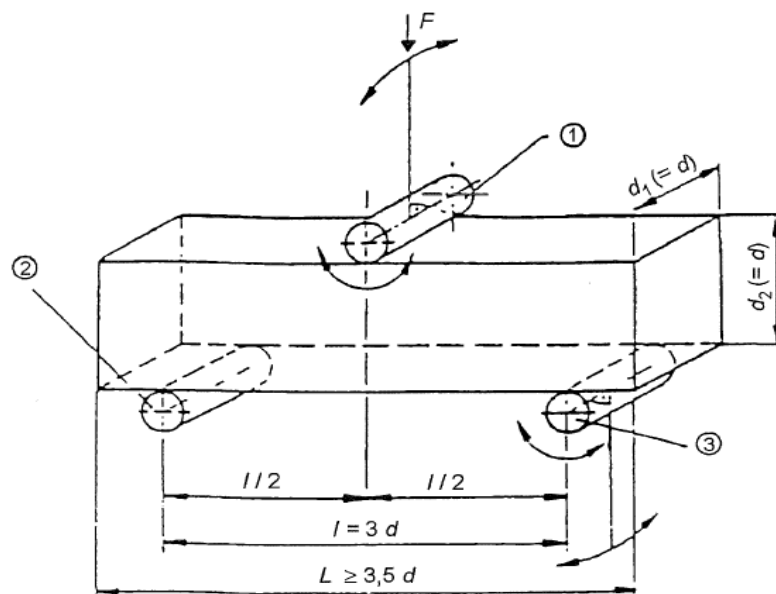


Figure 1. Schematic diagram of testing the SFRC specimen [8].

To better understand the behavior of test specimens during the three-point bending test, the acoustic emission method was used. The acoustic emission method, as an unusual non-destructive method, can often be used to detect a failure at a very early stage of damage long before the structure completely fails [9,10]. The paper also presents experiments focused on analyzing acoustic emission (AE) signals captured during commonly used three-point bending tests of specimens of SFRC without centre notch [11,12].

3. Experiment

The aim of the experiment was to compare the results of the tensile strength in bending tests on test specimens with dimensions of $100 \times 100 \times 400$ mm from three different SFRC formulas. The test used

was the so-called three-point bending test, in which the specimen is placed on two supports at a distance of 300 mm apart and loaded with an isolated load in the middle of the span according to CSN EN 12390-5 [8]. The formulas of SFRCs differed only in the concentration of steel fibres, and from each formula, 3 test specimens were prepared. As has already been mentioned, SFRC is also used in military defensive structures [13, 14]. Considering the use of the proposed formulas for building structures of this type, we chose concentrations of 40 kg/m^3 , 80 kg/m^3 and 120 kg/m^3 . The composition of individual mixtures and properties of steel fibers used are given in table 1 and table 2.

Table 1. Composition of the mixtures.

SFRC mixture	Cement 42.5 R	Water	Water ratio	Aggregates			Plasticizer	Steel fibers
	[kg/m^3]			0 – 4 [kg/m^3]	4 – 8 [kg/m^3]	8 - 16 [kg/m^3]		
T 1	390	160	0.41	900	250	670	4	40
T 2	390	160	0.41	900	250	670	4	80
T 3	390	160	0.41	900	250	670	4	120

Table 2. Properties of the steel fibers.

Fibers	Length [mm]	Diameter [mm]	Tensile strength [N/mm^2]	Young's modulus [N/mm^2]
DRAMIX RC-65/35-BN	35	0.55	1.345	210.000

The acoustic emission measurements were performed by means of an acoustic emission measuring system XEDO made by DAKEL (Czech Republic). This system comprised five channels. The guard sensor eliminated mechanical and electrical noise. In this study, four acoustic emission sensors of the MIDI type (made by DAKEL) were used, all having the same frequency range, and they were attached to the surface by beeswax [15].

4. Results and discussion

The following figures show the processed average diagrams of the dependence of the force on deformation $F_{Ri} - \delta_{ti}$. Also marked are the average values of forces $F_{Rk, 0.5}$ with an agreed deflection of $\delta_{t,0.5} = 0.5 \text{ mm}$, and force $F_{Rk,res,1}$ with an agreed deflection limit of $\delta_{t1} = 3.5 \text{ mm}$. It is apparent from the diagrams that increasing the concentration by 40 kg/m^3 causes both an increase in the tensile strength in bending, and an increase in the load capacity after the occurrence of a crack. Figure 1 shows the average diagram $F_{Ri} - \delta_{ti}$ for a concentration of 40 kg/m^3 – set of specimens T1. This diagram is typical of common structural SFRC concrete, in which the occurrence of a crack is followed by a significant decrease in strength, but thanks to the ductility and activation of steel fibres, the load capacity of the element decreases slowly. The maximum force was $F_{max} = 16.7 \text{ kN}$ and it was achieved at a deflection of $\delta_t = 0.2 \text{ mm}$.

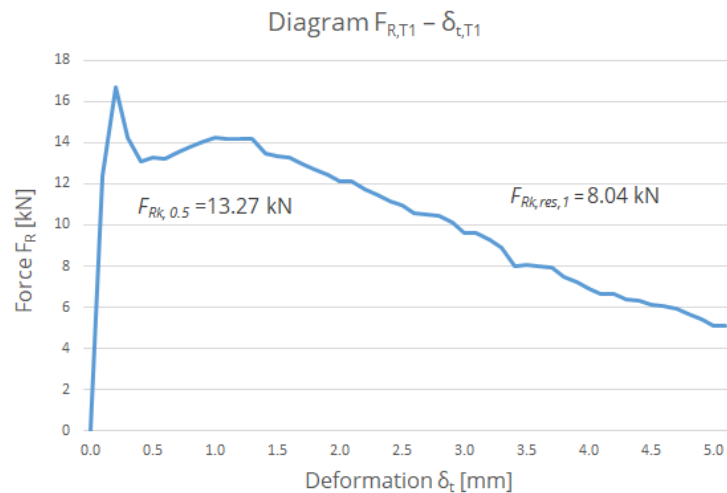


Figure 2. Average diagram of resistance for T1.

From the results of testing the T2 set of specimens (80 kg/m^3) and from their average diagram $F_{Ri} - \delta_{ti}$ it is possible to conclude that the overall load capacity was increased, and force $F_{Rk,0.5}$ at a prescribed deflection of $\delta_{t,0.5} = 0.5 \text{ mm}$ is at the same time equal to the maximum achieved force of F_{\max} under loading. The very progress of the average diagram suggests that during the tests, steel fibres performed their function and were not pulled out.

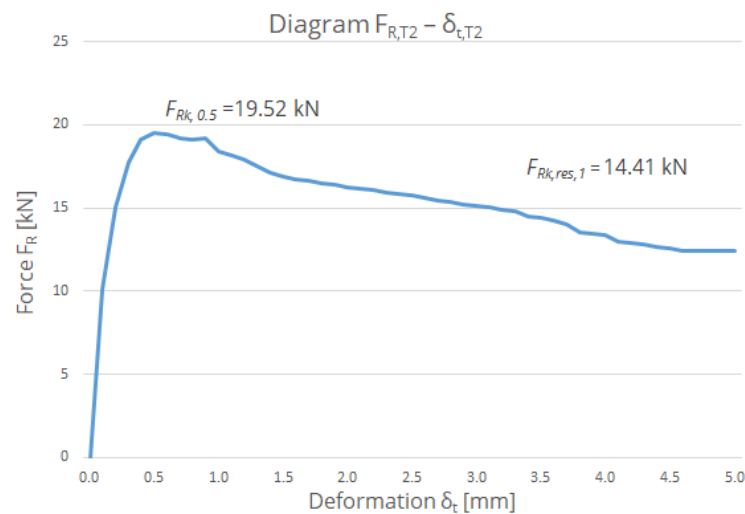


Figure 3. Average diagram of resistance for T2.

In the T3 set of specimens (120 kg/m^3), the achieved maximum force was $F_{\max} = 22.5 \text{ kN}$ at a deflection of $\delta_t = 1.1 \text{ mm}$. For the specimens of the given dimensions and with this concentration, it seemed to be problematic to guarantee their homogeneity. Nevertheless, the progress of the average diagram in figure 4 shows that homogenous SFRC specimens were manufactured even with such a high concentration. Overall, it is possible to say that at a concentration of 120 kg/m^3 , the SFRC concretes have a high load capacity and above all, ductility.

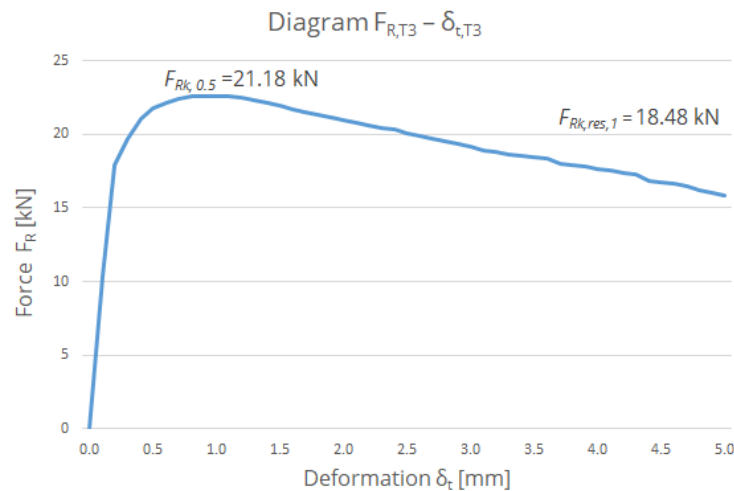


Figure 4. Average diagram of resistance for T3.

Acoustic emission signals which were received during the three-point bending testing of the specimens in the course of the entire measurement were analyzed. The attention was focused on three basic parameters: the number of events, and the amplitude and duration of the AE signals table 3.

Table 3. Mean values of the selected parameters obtained from AE measurements (coefficients of variation in %).

	Number of AE events /–	Amplitude of AE signals /mV	Duration of AE signals /μs
T1	10218 (1.17)	1647 (0.05)	1684 (0.03)
T2	11780 (1.16)	1601 (0.06)	1544 (0.04)
T3	14353 (1.18)	1585 (0.05)	1529 (0.05)

When the AE sensor captures a signal over a certain level, an AE event is recorded. The occurrence of a large number of cracks generates a rather large number of events during measurement. The highest number of events was shown by the T3 specimens with the greatest amount of steel fibres. As the amount of steel fibres decreases, the number of AE events becomes slightly lower. The amplitude is the greatest measured voltage in a waveform. This is an important parameter in the AE inspection because it determines the detectability of the signal. Signals with amplitudes below the operator-defined minimum threshold are not recorded. A higher amplitude indicates the occurrence of a larger and more significant crack. The amplitude values varied between 1585 and 1647 mV after 65 dB amplification. With the increased amount of steel fibres, the amplitude slightly decreased. The duration of an AE signal is the time difference between the crossing of the first and the last threshold. The duration of AE signals achieved for specimens with a higher amount of steel fibres was lower compared to the specimens with a lower amount of steel fibres. Nevertheless, the decrease in the duration of AE signals with increasing amounts of steel fibres was not so significant.

5. Conclusion

The paper presented the results of performed experiments which confirmed dependencies of the resulting mechanical properties of SFRC on the technological process of its production. With unusually high concentrations of steel fibres (40 kg/m³, 80 kg/m³ and 120 kg/m³), which were used in this experiment, it was possible to manufacture homogenous SFRCs with very high values of load capacity at prescribed deformations. The results can be summarized as (related to 40 kg/m³):

- the value of $F_{Rk,0.5}$ increased about 47 % (80 kg/m³) and 60 % (120 kg/m³),

- the value of $F_{Rk, res, 1}$ enlarged about 79 % (80 kg/m^3) and the mixture with 120 kg/m^3 of fibres even about 130 %.

The resulting values of parameters of AE signals captured during the loading tests correspond very well with the results of the strength tests, thanks to which this method seems to be suitable for a better understanding of the behaviour of test specimens under loading with controlled deformations.

Acknowledgement

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